DETERMINATION OF ROCK STRENGTH FROM SLAKE DURABILITY TESTS, PROTODYAKONOV IMPACT TESTS AND LOS ANGELES ABRASION RESISTANCE TESTS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Mining Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled **"DETERMINATION OF ROCK STRENGTH FROM SLAKE DURABILITY TESTS, PROTODYAKONOV IMPACT TESTS AND LOS ANGELES ABRASION RESISTANCE TESTS**" submitted by Sri Chinmoy Swain, roll no-10605009 for partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering, National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: **(Dr. MANOJ KUMAR MISHRA)**

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ABSTRACT

The growing needs has been pushing the limits, to which the mining industry has to lift itself to fulfill the demand. Hence it requires advanced technology and proper geological studies to carry out any mining operation. In mining operations we deal mainly with hard rocks with different mechanical properties and varying strengths. Research in geology and rock mechanics is done to elucidate the influence of the rock index properties in determining the strength, durability, crushability and nature of the rock. This paper throws light on the prediction of the rocks behavior and nature of the rocks when it is subjected to varying conditions of atmosphere and sudden impacts of load. It also deals with the abrasion resistance offered to other rocks and its cohesiveness of the rock.

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CHAPTER 1

Introduction

Aim of the study

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CHAPTER -1

1.0 INTRODUCTION

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body or seam. Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash. Any material that cannot be created by any methods or grown by any agricultural process is achieved by mining. Mining in a wider sense comprises extraction of any non-renewable resource.

Mining of stone and metal has been done since pre-historic times. Modern mining methods include a set of process to open a mine and carry out operation in it. It usually involves geological investigation, prospecting, analyzing the amount of resource that can be extracted from it, calculate the profit-loss scenario basis, opening of a mine, carrying out extraction processes and finally closing a mine by reclamation. Though the mining activities provide a rich dividend to the humans but it has equally harmful and negative impacts on the environment and the humans directly and indirectly. Due to this various nations throughout the world has adopted set of regulations for mining activities in their respective countries. Even after adopting various measures of safety , accidents and mishaps are still associated with mining.

1.1 AIM OF THE STUDY

The goal of the present investigation is to determine the correct strength values for design purposes and provide safety in workings and excavations.

1.2 OBJECTIVES OF THE STUDY

In order to achieve the aim the following objectives has to be carried out.

- To critically understand the properties and nature of the rocks.
- Critically analyze the relationship between various parameters determining the strength of rocks.
- To determine the slake durability index, protodyakonov index and the los angels abrasion loss test for a few samples of coal and sandstone.

1.3 METHODOLOGY

The above objectives could only be reached if acted upon with a planned approach. The first step towards a goal always starts with knowing everything about it. Thus I began with the literature review. The books, journals, papers proved a rich source of knowledge in this regard and were thoroughly studied and learned.

This was followed by collection of the data from the field. Samples from many sample points were collected and carefully packed and sent to the laboratory for the analysis.

After the sample collection the samples were prepared for laboratory testing.

The collected samples were undertaken various analysis to know about the sample properties like slake durability index, protodyakonov index and Los Angeles abrasion loss test.

Results were found out from these experimentation by calculations and then these sample properties were used in the analyses.

Conclusions were drawn from the results and analysis and future recommendations for better safety were given.

1.4 SAMPLING

1.4.1 Significance

The dimensional, shape, and surface tolerances of rock core specimens are important for determining rock properties of intact specimens. This is especially true for strong rocks. Hence various tests are carried out to determine the strength parameters of the rocks and analyze its deformation characteristics.

The amount of moisture of the specimen at the time of the preparation of sample can have a significant effect upon the strength and deformation characteristics of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of insitu conditions. So that the actual conditions and moisture content in the specimen remains intact during laboratory testing. Still, there may be reasons for testing specimens at other moisture contents, from saturation to dry. So its better to know the moisture conditions so it can be handled properly. Excess moisture will affect the adhesion of resistance strain gauges, if used, and the accuracy of their performance. Adhesives used to bond the rock to steel end pieces of the apparatus in the direct tension test will also be affected adversely by excess moisture in the sample.

Specifying procedures for laboratory rock test specimen preparation of rock core from drill core and block samples for strength and deformation testing and for determining the conformance of the test specimen dimensions with tolerances established.

Rock cores are the sample of record which gives the actual existing conditions of the field and at particular borehole location. The samples are expected to yield significant indications about the geological, physical, chemical and engineering nature of the subsurface for use in the design and construction of an engineered structure. The core samples need to be preserved using specific procedures for a stipulated time so that it can reflect the actual conditions of the field. The period of storage depends upon the nature and significance of the engineered structure and the type of laboratory testing to be carried out.

Rock cores always need to be handled and preserved such that their properties are not altered in any way due to mechanical damage or changes in ambient conditions of moisture and temperature or other environmental factors.

- This practice covers the guidelines, requirements, and procedures for core drilling, coring, and sampling of rock for the purposes of site investigation.
- The coring of the borehole could be vertical, horizontal, or angled.
- This practice applies to core drilling in hard and as well as soft rock.
- The values that are given in inch-pound are taken as standards while the values which are mathematically converted to SI units are not to be taken as standard.
- This practice does not support to comprehensively address all of the methods and the issues associated with coring and sampling of rock.
- Persons with proper knowledge and skills of using the equipment to perfect use should be involved in carrying out this process.

1.4.2 Storage

- The samples collected from the site were kept at a separate place.

- These samples are either kept for insitu testing or laboratory testing.
- The samples for insitu testing are directly used at the site.
- Some samples which will be taken for laboratory testing is kept in plastic bags.
- Plastic bags are used to protect it from moisture and the atmosphere gases.

1.4.3 Transportation of Samples

- Transportation of samples is usually done in trucks, lorries etc.
- Samples which are collected in plastic bags which stop interaction of the samples with the external atmosphere are kept in wooden boxes.
- The wooden boxes have around 3-4 shelves.
- Wooden boxes are usually preferred during the transporting of the rock samples because the protect the samples from sunlight.
- Heat of the sun during transportation of the samples can cause fire in the coal samples if exposed directly. Hence wooden boxes protect the samples efficiently.
- Wooden boxes also protect them from rainfall and reduce the chances of faulty samples in the laboratory testing.
- Wooden boxes along with the plastic bags preserve the true nature of the samples from the site to the laboratory.

1.5 TESTING

The most vital and essential scope in rock mechanics is measuring and determination of rock properties and behavior by using the recommended testing methods, procedures, and specifications. These include the engineering characteristics of rock such as its strength, mode of deformation, mode of failure, and modulus of elasticity, sonic velocity index, tensile strength etc.

A study upon rock in rock mechanics is one of civil and mining subject disciplines. Rocks are inhomogeneous and anisotropic in nature and though it is collected from the same places its still shows variations in properties and nature.

Generally there are two common categories for testing of rock samples:

- Laboratory testing which is done at the lab with the rock samples obtained from the selected locations,
- Field or In-situ testing which is done by operating directly at the site itself.

1.5.1 Laboratory Testing

Laboratory testing is done to determine the various rock strength properties, indices and other parameters which define the nature of the rock. The samples collected from the filed are properly preserved for laboratory testing so the true nature of the rocks is not altered. As stated before, the two most common methods of laboratory testing for rock are:

1) Index test, and Indirect Strength test;

2) Direct or Strength test.

1.5.1.1 Index Test and Indirect Strength Test

Index test is relatively simple in nature and and can be conducted in a limited, but it does not provide fundamental property. The results obtained is just an indicator on property that being tested. The apparatus used are normally simple and portable which also allows the test to be conducted at site.

The preparation of the samples for the indirect strength test and the Index test are easy to prepare and less time consuming as compared to direct strength tests.(cost saving for sample could be reused). Though the results and data obtained from the testing does not provide detail information about the designing of structures but is useful in conveying valuable information for the feasibility of the structure and its preassessment.

The tests for Index and Indirect Strength test include:

- Point-load index test
- Schmidt or Rebound hammer test
- Slake durability index test
- Sonic wave velocity test

- Uniaxial compressive strength test
- Brazilian or Indirect tensile strength test

1.5.1.2 Point-Load Index Test

It is a quick and simple test to conduct where the rock sample can be in core or irregular block. The equipment is easy to use and handle as test could be perform directly on site.

1.5.1.3 Schmidt or Rebound Hammer Test

It normally tests on surface hardness of rock sample as it is also easy to use and handle. The sample can be in core or in block shape and it is non-destructive type of test. The best part of the test is that the sample used for the previous test can be used again.

1.5.1.4 Slake Durability Index Test

The slake durability test is useful in determining the disintegration nature of the rocks when it is subjected to drying and wetting conditions along with movement. This test properly defines the weathering behavior of rocks.

1.5.1.5 Sonic Wave Velocity Test

This test is non-destructive and the equipment is portable. In this test primary waves is transmitted through rock core samples and the wave propagation velocity is noted and used for analysis.

1.5.1.6 Brazilian or Indirect Tensile Strength Test

The objective of this test is to measure uniaxial tensile strength of rock sample indirectly using Brazilian test.

1.5.1.7 Direct Test or Strength Test

Direct test involves detailed sample preparation and minute finishing of the samples. It is time consuming as sample preparation is detailed and the type of sample preparation also depends upon the test carried out and the equipment used for testing. The testing itself involves sophisticated and large equipment significant to the detailed testing procedures and may require complex analysis and this is also costly.

However, the data obtained is the basic fundamental property and would be the direct presentation of property being evaluated. The number of tests are made limited due to the costly testing methods and the data sand results obtained can be used directly for designing puroses,

The tests for Direct or Strength test include:

- Permeability of rock
- Modulus of deformation
- Uniaxial and Triaxial compressive strength test
- Shear strength test

1.5.1.8 Uniaxial Compressive Strength Test

It requires a preparation of sample as accordance to ISRM (International Society of Rock Mechanics). Uniaxial compressive strength (UCS) of rock material and deformation behavior under loading is verified by applying compressive load until failure occurs in the core by a fracture in the middle using high capacity Universal testing machine (UTM).

1.5.1.9 Triaxial Compressive Strength Test

Triaxial compressive strength test is used to know the strength of the rock when it is compacted in 3 directs i.e. rocks under confinement condition; example rock samples obtained from deep seated rock mass.

1.5.1.10 Shear Strength Test

It mostly deals with the shear strength and shear behavior of the shearing and weakness planes of the rock which hold together a rock specimen. This is the most expensive laboratory strength tests, as it requires special kind of methodology for acquiring the samples from the site as fracture planes to be tested and utmost relatively complex testing procedures. The weakness planes shear strength, fractures, failures, dents and joints in rock mass is important for project which involves excavation in rock such as slopes and tunnels.

1.5.2 Field or In-situ Testing of Rocks

The testing approach is to assess the rock properties and nature at the site scene where it is found. It will include large-scale of direct strength test on site as the preparation and the equipment involved in testing could be expensive, complex, and time-consuming.

In-situ strength tests are undertaken when properties of rock are very critical to the design and detailed assessment under the actual environment is considered essential. The cost involved in undertaking the test can be seen in the anticipated behavior of the unstable block with regards to nature of the project and the surrounding of rock mass.

The main advantages of field full-scale test are:

- It involves larger size of sample as inclusive of large-scale discontinuities.
- In-situ sample is undisturbed and more representative of the actual field condition.

The disadvantages of the insitu testing are

- It is costly as compared to the laboratory testing.
- It is difficult to carry out the testing in field.
- It yields less accurate results though it is more representative of the actual field condition.

CHAPTER 2

Rock Hardness

Mineral Hardness

Physical properties of rocks

CHAPTER 2

2.0 ROCK HARDNESS

Rock hardness is a term used in geology to denote the cohesiveness and bonding of a rock and is usually expressed as its compressive fracture strength. Terms such as hard rock and soft rock are used by geologists in distinguishing between igneous/metamorphic and sedimentary rocks, respectively. This terms of hard rocks and soft rocks originated from historical mining methods which were used to mine an ore deposit.

Rocks can be tested for their unconfined fracture strength by using ASTM standard tests. The fracture strength of a rock is defined as a maximum stress that can be subjected to the core sample to induce failure in it. This value gives an indication of the cohesiveness, bonding nature and density of a rock, igneous, metamorphic and sedimentary rocks can be classified from very weak to very strong with regards to their unconfined fracture strengths.

Table 1. Classification of rock hardness

Strength classification	Strength range (MPa)	Typical rock types
Very weak	10-20	weathered and weakly-compacted sedimentary rocks
Weak	20-40	weakly-cemented sedimentary rocks, schists
Medium	40-80	competent sedimentary rocks; some low-density coarse-grained igneous rocks
Strong	80-160	competent igneous rocks; some metamorphic rocks and fine-grained sandstones
Very strong	160-320	quartzites; dense fine-grained igneous rocks

Source : (Attewell & Farmer 1976)

It can be seen that each rock type can exhibit considerable variations in their properties. These variations are the result of a number of factors, which include porosity, grain size, grain shape, grain and crystallographic preferred orientation, mineralogy, permeability, magnetic behavior and moisture content. In most rocks the main factors controlling rock hardness are porosity, bonding material, grain size, and grain shape. All of these factors affect the surface area of the interlocking bond forces at mineral grain to grain contacts. In most rocks, the rock hardness depends upon the surface area of grain to grain contact and it is directly proportional to it.

2.1 MINERAL HARDNESS

Mohs' scale of hardness represents a scale of relative mineral hardness rather than a scale of absolute mineral hardness. The key word here is "relative"... what this means is that because Moh’s Scale does not actually represent the true values of harndness. It is a list of 10 common minerals that increase in hardness as one ascends the list. It is more of a comparison scale to determine harndess of the minerals. It was originally designed by Fredrick Mohs in the early 19th century to be use in combination with a number of other diagnostic tests and observations for mineral identification by geologists and mineralogists. On Mohs' scale a mineral will scratch another mineral of equal or lesser hardness than itself. This allows the 10 common minerals of Mohs' scale to be used to make a simple scratch test to grade that an unknown mineral can scratch or be scratched by another, and in so giving a rough estimate of relative hardness. This test allows the unknown mineral's relative hardness to be compared to a list of known relative mineral hardness to help in identification. As a result Mohs' scale is usually graduated only to 0.5 or 0.25 intervals. In order to compare absolute mineral hardness one must use other methods.

Table 2: Moh’s scale of hardness

MINERAL	MOH’S SCALE OF HARDNESS
TALC	1
GYPSUM	2
CALCITE	3
FLOURITE	4
APATITE	5
ORTHOCLASE	6
QUARTZ	7

TOPAZ	8
CORUNDUM	9
DIAMOND	10

2.2 PHYSICAL PROPERTIES OF ROCKS

1) **Porosity**-Porosity is a measure of the void spaces in a material, and is mathematically defined as a fraction of the volume of voids over the total volume, between 0–1, or as a percentage between 0–100 percent. The term is used in multiple fields including pharmaceutics, ceramics, metallurgy, materials, manufacturing, earth sciences and construction and even in rock mechanics.

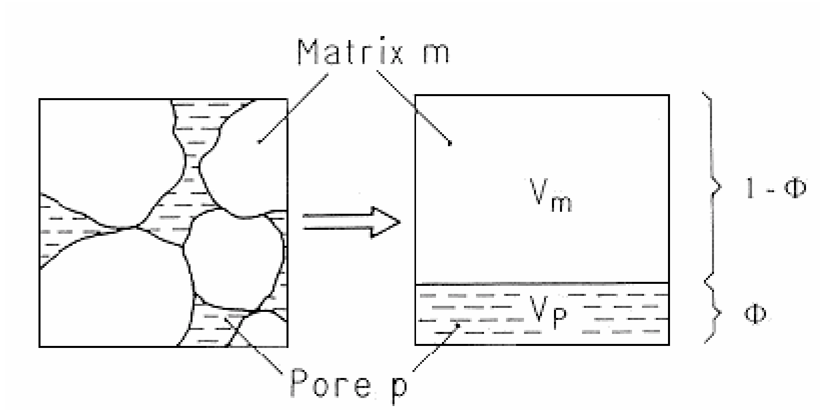
Used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium (such as rock or sediment) describes the fraction of void space in the material, where the void may contain. It is defined by the ratio

$$\text{Porosity} = V_v/V_t$$

where V_V is the v of void-space (such as fluids) and

V_T is the total or bulk volume of material, including the solid and void components of the material. Both the mathematical symbols φ and *n* are used to denote porosity.

Fig1. Pore volume and pore spaces



(Source : GOPH365 – JM MAILLOL – 2001)

2) **Density** -The density of a material is defined as its mass per unit volume. The symbol of density is ρ (the Greek letter rho).

Mathematically:

$$P = m/V$$

where:

ρ (rho) is the density,

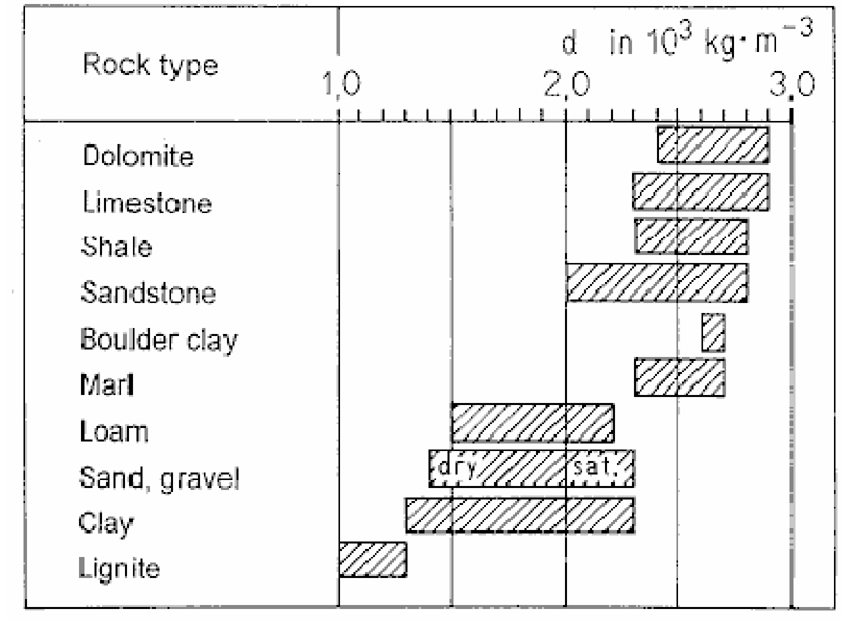
m is the mass,

V is the volume.

Different materials usually have different densities, so density is an important concept regarding buoyancy, packaging and metal purity.

In some cases density is expressed as the dimensionless quantities specific gravity (SG) or relative density (RD), in which case it is expressed in multiples of the density of some other standard material, usually water or air/gas.

Table 3. Density of various rocks



(Source : GOPH365 – JM MAILLOL – 2001)

3) **Specific gravity** - Relative density, or specific gravity, is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference material. Specific gravity means relative density with respect to water.

If a substance's relative density is less than one then it is less dense than the reference; if greater than one then it is denser than the reference. If the relative density is exactly one then the densities are equal; that is, equal volumes of the two substances have the same mass. If the reference material is water then a substance with a relative density (or specific gravity) less than one will float in water.

Relative density (RD) or specific gravity (SG) is a dimensionless quantity, as it is the ratio of either densities or weights

$RD = \rho_{substance} / \rho_{reference}$

where *RD* is relative density, $\rho_{substance}$ is the density of the substance being measured, and $\rho_{reference}$ is the density of the reference. (By convention ρ, the Greek letter rho, denotes density.)

4) **Permeability** - Permeability in fluid mechanics and the earth sciences (commonly symbolized as κ, or k) is a measure of the ability of a porous material (often, a rock or unconsolidated material) to transmit fluids.

The intrinsic permeability of any porous material is:

$$K_i = C \cdot d^2$$

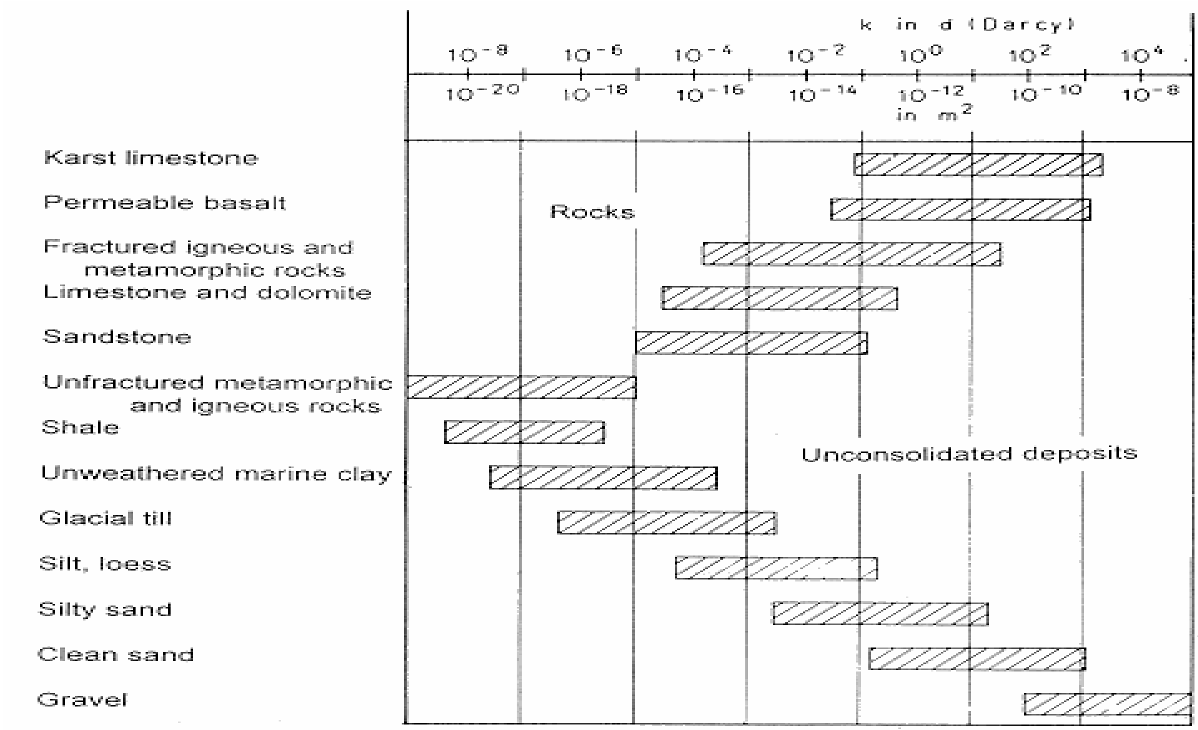
where

κ_I is the intrinsic permeability [L^2]

C is a dimensionless constant that is related to the configuration of the flow-paths

d is the average, or effective pore diameter [L]

Table 4. Permeability of different rocks



(Source : GOPH365 – JM MAILLOL – 2001)

5) **Water content** - Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, or wood on a volumetric or gravimetric basis. The property is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation.

Volumetric water content, θ, is defined mathematically as:

$\theta = V_w/V_T$

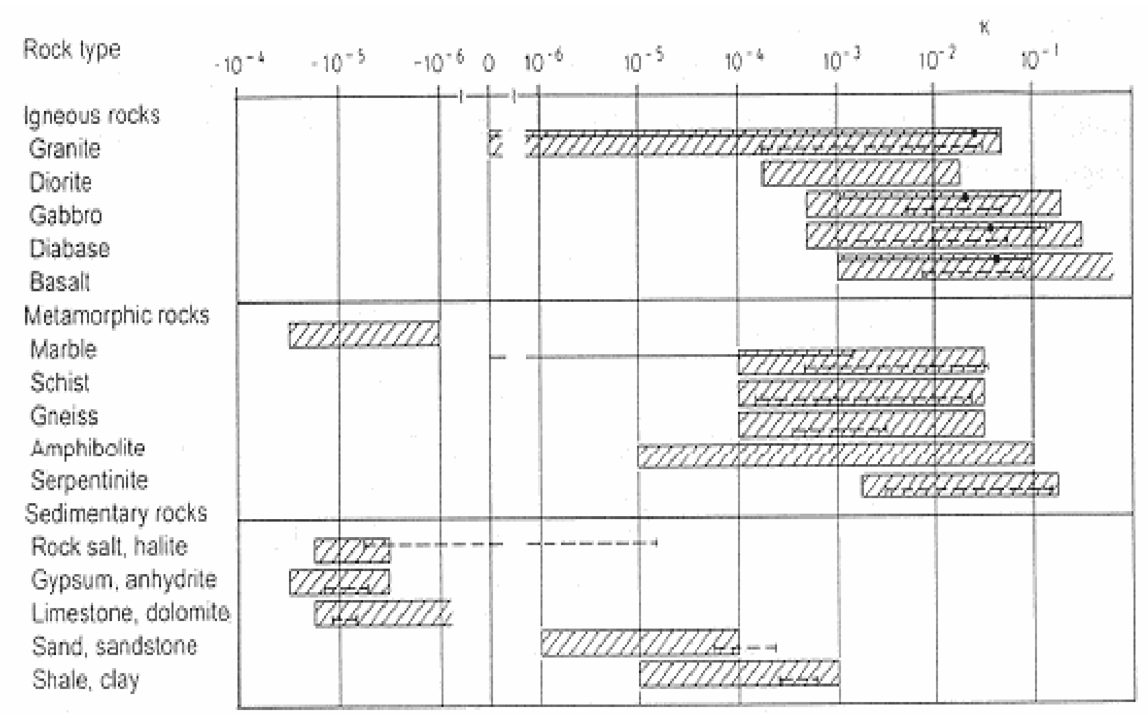
where V_w is the volume of water and $V_T = V_s + V_v = V_s + V_w + V_a$ is the total volume (that is Soil Volume + Water Volume + Void Space). Water content may also be based on its mass or weight.

6) **Slake durability index** -A test to estimate the resistance of rocks, particularly argillaceous rocks, to a combination of wetting and abrasion. Test results are expressed as a slake durability index for each particular rock. The slake-durability test is regarded as a simple test for assessing the influence of weathering on rock.

7) **Sonic velocity index** -In a solid, there is non-zero stiffness both for volumetric and shear deformations. Hence, it is possible to generate sound waves with different velocities dependent on the deformation mode. Sound waves generating volumetric deformations (compressions) and shear deformations are called longitudinal waves and shear waves, respectively. In earthquakes, the corresponding seismic waves are called P-waves and S-waves, respectively.

8) **Susceptibility** -It is a function of percentage of ferromagnetic minerals (magnetite…) present in the rock and it is one of the most variable physical properties.
K= M/H where M= induced magnetization, H= applied magnetic field strength
It is dimensionless.

Table 5. Susceptibility of various rocks



(Source : GOPH365 – JM MAILLOL – 2001)

9) **Electrical properties (electrical conduction)** - Ohm's law describes conduction currents: $E = \rho J$

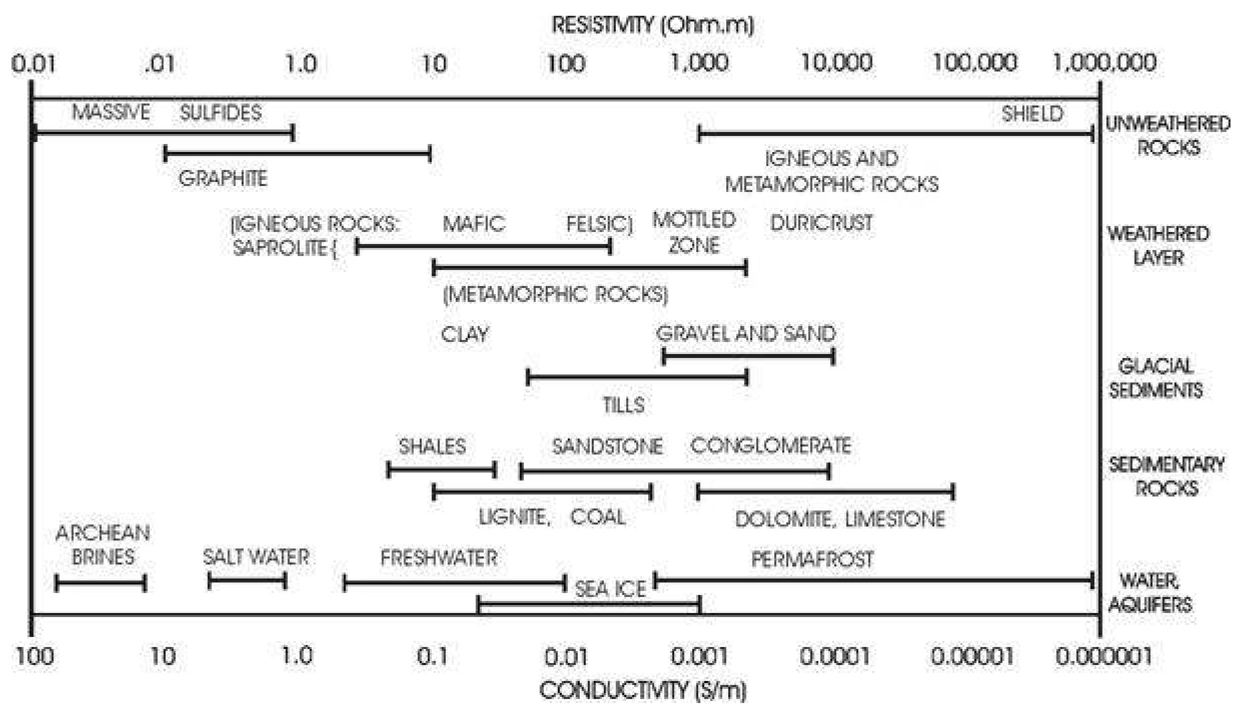
E= electric field, J=current density, ρ = electrical resistivity

It can also be written: $J = \sigma E$ where σ is the electrical conductivity ($\sigma = 1/\rho$);

ρ is expressed in Ohm-m (Ω-m) and σ is expressed in Siemens/meter (S/m)

Resistivity has a broad range of variation. Minerals are generally very resistive so the resistivity of rocks is essentially controlled by water, especially in sedimentary rocks and unconsolidated sediments. In the latter, direct relationships exist between porosity and resistivity/conductivity (Archie's "law"). In general resistivity increases when porosity increases.

Table 6. Electrical conductivity of various rocks



(Source: GOPH365 – JM MAILLOL – 2001)

CHAPTER 3

Tests conducted

Slake durability test

Protodyakonov Test

Los Angeles Abrasion Test

CHAPTER 3

3.0 TESTS CONDUCTED

To achieve the objectives of the study the following experiments were done to know the nature and indices of the coal samples and sandstone samples.

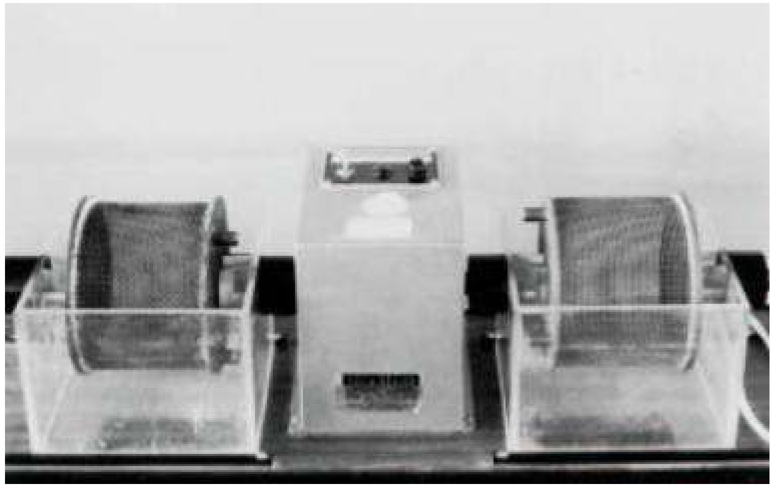
1) SLAKE DURABILITY INDEX
2) PROTODYAKNOV TEST
3) LOS ANGELES ABRASION RESISTANCE TEST

3.1 SLAKE DURABILITY TEST

The slake-durability test is regarded as a simple test for assessing the influence of weathering on

Rock and its disintegration. However, mechanisms involved in this slaking test have not been fully understood yet even after so many years. The mechanisms movements of the rocks inside the apparatus are understood but its effect on weathering is still unknown. Franklin and Chandra indicated that mechanisms in slake-durability tests are subjected to ion exchange and capillary tension. For rocks containing clay materials, the exchange of cations and anions take place with the adsorption and absorption of water which makes the rock swell in size and slaking occurs. With the duration of the test of only ten minutes, the wetting process may only take for parts of the rock, particularly for the surface part but due to appropriate rotation speed and the level of the water most of the parts of the rocks get wet.

Fig 2 .Slake durability test apparatus



When the rock becomes more saturated, water menisci within the rock pores increase, which then causes the reduction of capillary tension at grain contacts and the tips of cracks. Due to the increase in the water content in the pores, fracture develops in the rock which leads to the weathering of rocks. This mechanism seems to dominate the durability behavior of porous rock. Water certainly influences the mechanical characteristics of rock. However, in the slake-durability test, not only wet-dry conditions are given to the rock specimen, but also mechanisms correspond to the drum rotation are involved. These mechanisms have not been explored. Such mechanisms may be influenced by the shape and weight of the specimen. Therefore the main objective of the study is to determine the slake durability index of the rock samples rather than analyzing the mechanisms of the specimen.

3.1.1 Method

The slake-durability test was intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting.

- Rock samples were put into an apparatus that comprises two sets of drums of the length of 100 mm and the diameter of 140 mm.

- The two drums rotated in water that had a level of about 20 mm below the drum axis.

- The rotation was driven by a motor capable of rotating the drums at a speed of 20 rpm, which was held constant for a period of 10 minutes.

- Ten rock lumps, each had a mass of 40-60 g, were placed in the drums.

- After slaking for the period of 10 minutes, these rock samples were then dried in an oven at a temperature of 105 degree centigrade for up to 6 hrs.

- Finally, the mass of dried samples was weighted to obtain the first cycle. The test was conducted over two cycles, in which the weight of particles of 10 rock lumps retained in these wet-dry cycling tests was therefore determined.

Table 7. Gamble's table

Gambles' Slake Durability Classification (Goodman, 1980)

Group Name	% retained after one 10 min cycle (dry weight basis)	% retained after two 10 min cycle (dry weight basis)
Very High Durability	> 99	> 98
High Durability	98 - 99	95 – 98
Medium High Durability	95 – 98	85 – 95
Medium Durability	85 – 95	60 – 85
Low Durability	60 – 85	30 – 60
Very Low Durability	< 60	< 30

3.1.2 Method Of Calculation

- Initial weight taken = A
- Weight after 1st cycle = B

- Weight after 2^{nd} cycle = C
- % retention after 1^{st} cycle =(A-B)/A x 100
- % retention after 2^{nd} cycle=(B-C)/B x 100

3.2 PROTODYAKONOV IMPACT STRENGTH TEST

Protodyakonov Impact Strength Index (PSI) is a way of characterizing coal strength, which has immense possibility for practical implementation in coal cutting and drilling. It also gives an idea about the uniaxial compressive strength of the rock.

3.2.1 Method

Impact strength index test is first discovered by Protodyakonov to put forward an idea about the Rock's strength properties, cuttability and brittleness, then is improved by Evans & Pomeroy (1966)

- This technique is based upon the crushability of rock under standard experimental condition.
- This test is performed by a vertical cylinder apparatus which is 30 48 cm in height and has a steel plunger.
- 100 gm of sample is taken of size -4.75 mm to + 3.35 mm is taken in the cylinder.
- 50 gm of sample is taken if the sample is coal.
- A plunger is dropped from a height of 65 cm into the cylinder in which the sample is kept.
- The weight of the plunger taken is around 2.4 kg.
- The plunger is dropped 20 times in the cylinder if the sample is rock and 15 times if the sample is coal.
- The crushed sample is collected and is sieved through 0.5 mm sieve.
- The -0.5 mm sample is collected and filled in the volumeter.
- The height "h" in the volumeter is measured.
- Protodyakonov impact strength index is found out by using the following formulae.

P.S.I = (20 x n)/h

Where

P.S.I = Protodyakonov strength index

n = no of blows

h = height in the volumeter

Fig 3. Coal sample after sieving Volumeter

3.2.2 Method of Calculation

- Initial weight of sample =50 gms for coal
- Initial weight of sample =100 gms for rock

- Height in volumeter = h
- No of blows = n = 15 for coal
- No of blows = n = 20 for rock

- P.S.I = 20 x n/h

3.3 LOS ANGELES ABRASION TEST

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities. Aggregates not adequately resistant to abrasion and polishing may cause premature structural failure and/or a loss of skid resistance.

The L.A. abrasion test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres .As the drum rotates the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres (called the "charge"). Once the test is complete, the calculated mass of aggregate that has broken apart to smaller sizes is expressed as a percentage of the total mass of aggregate. Therefore, lower L.A. abrasion loss values indicate aggregate that is tougher and more resistant to abrasion.

Fig 4 .Steel balls used in Los Angeles abrasion resistance test

(Source :Bull. Mater. Sci., Vol. 31, No. 2)

The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics.

The standard L.A. abrasion test subjects a coarse aggregate sample (retained on the No. 12 (1.70 mm) sieve) to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres.

Fig 5. Los Angeles apparatus

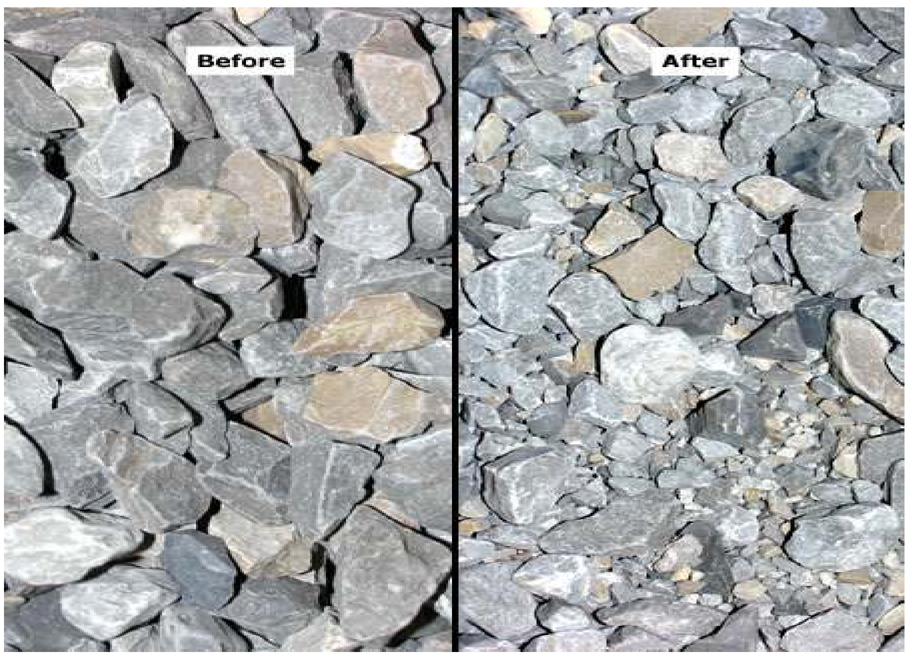
3.3.1 Method

ASTM method C 131-66 was used for the LA abrasion test.

- Test samples were oven-dried at 105–110°C for 24 hrs and then cooled to room temperature before they were tested.

- There are four aggregate sizes grading to choose from in the ASTM method.
- After drying, sieve the material into individual size fractions, and recombine to one of four specified grading that most nearly represents the aggregate gradation as received. Record the total sample mass. The total sample mass should be about 5000 g.
- Six steel spheres were placed in a steel drum along with ~ 5000 g of aggregate sample.
- The drum was rotated for 500 revolutions at a rate of 30–33 rev/min.
- After the revolution was complete, the sample was sieved through the 1.7 mm sieve.
- The amount of material passing the sieve, expressed as a percentage of the original weight, was
- The LA abrasion loss or percentage loss was noted.

Fig 6. Sample before and after los angeles abrasion resistance testing



(Source :Bull. Mater. Sci., Vol. 31, No. 2)

Table 7: A typical Los Angeles abrasion test values

Rock types	**L.A abrasion loss**
General values	
Hard , igneous rocks	10
Soft , limestone and sandstones	60
Range for specific rocks	
Basalt	10-17
Dolomite	18-30
Gneiss	33-57
Granite	27-49
Limestone	19-30
Quartzite	20-35

(Source :Bull. Mater. Sci., Vol. 31, No. 2)

3.3.2 Method Of Calculation

- Initial weight = 5000 gms
- Weight of sample after sieving = L

% LOSS = (5000- L)/5000 x 100

CHAPTER 4

Results, Analysis and conclusions

Slake Durability Test

Protodyakonov Test

Los Angeles Abrasion Test

CHAPTER 4

4.0 RESULTS ,ANALYSIS AND CONCLUSIONS

4.1 SLAKE DURABLILITY TEST

The slake durability test was carried out with 8 coal samples. Initial weights of the coal samples were taken as given below in the table. Thus the various percentage of retention of the coal samples was found out.

It was seen that the coal sample percentage retention after the first cycle was found to be ranging between the values of 94.7% to 96.79 %.

While after the second cycle of the slake durability test it was found that the coal sample retention percentages ranged from 87.55% to 93.69%.

Table 9: Slake durability test tables for coal samples

SERIAL NO	INITIAL WEIGHT	WEIGHT AFTER 1ST CYLCE	WEIGHT AFTER 2ND CYCLE	%RETAINED AFTER 1ST CYCLE	%RETAINED AFTER 2ND CYCLE
1	499	474	415	95.18	87.55
2	498	472	425	94.7	90.04
3	501	482	434	96.20	90.04
4	500	476	441	95.2	92.64
5	500	473	435	94.6	91.96
6	501	478	428	95.40	89.50
7	499	483	444	96.79	91.92
8	500	476	446	95.2	93.69

Hence, taking the average of the retention percentages after the first cycle and the second cycle, the values of retention after the first cycle was found to be 95.40%, while the value after second cycle was found to be 90.91%.

Hence, comparing the average values found with the Gamble's table of classification, the coal samples were found to be medium high durable in nature.

Due to less available sandstone samples, only 2 tests were performed to know the durability of the sandstone. Initial weights were taken as given in the table and the slake durability tests was performed.

It was found that the values of the retention percentages of the sandstone samples after the first cycle were found to be ranging between 52% to 56%. The values of the retention percentages of the second cycle were found to be ranging between 46.10% to 48.57%.

Table 10: Slake durability test tables for sandstone samples

SERIAL NO	INITIAL WEIGHT	WEIGHT AFTER 1ST CYLCE	WEIGHT AFTER 2ND CYCLE	%RETAINED AFTER 1ST CYCLE	%RETAINED AFTER 2ND CYCLE
1	500	260	120	52	46.10
2	500	280	136	56	48.57

Hence comparing the values of the first cycle and second cycle in the gamble's table the sandstone sample was found to be very less durable.

The varying values of the sandstone and the coal sample is due to the reason that coal sample is extracted at greater depths as compared to sandstone. As it is found at places of greater depth, the overburden lying above it results in compaction of the coal which improves the inherent strength of the coal. On the other hand the sandstone sample was found to be very less durable due to greater grain size and less cohesiveness between the particles of sandstone. It may be also due to water soluble binding material in sandstone which gets dissolved easily and leads to weak sandstone sample.

4.2 PROTODYAKONOV IMPACT STRENGTH TEST

The protodyakonov test was carried out with coal and sandstone samples. The determination of protodyakonov impact strength index tells about the crushing strength of the rocks and also reflects about the compressive strength of the rocks.

For coal samples the number of blows was 15.The number of tests carried out for coal samples was three It was found that the height in the volumeter of the coal samples was ranging between 31 to 34 mm.

Table 11: Protodyakonov test table for coal samples

SERIAL NO.	WEIGHT OF SAMPLE	NUMBER OF BLOWS	HEIGHT OF FINES IN VOLUMETER(MM)	P.S.I	AVERAGE P.S.I.
1	50	15	32	9.375	
2	50	15	34	8.823	9.291
3	50	25	31	9.677	

The protodyakonov strength index was found out be ranging between 8.823 to 9.677. The average of the strength indices was found out which came to be 9.291.

The number of blows given to sandstone sample was 20. Due to less available sandstone samples 2 tests were done for determining the protodyakonov impact index.

Table 12: Protodyakonov test table for sandstone samples

SERIAL NO.	WEIGHT OF SAMPLE	NUMBER OF BLOWS	HEIGHT OF FINES IN VOLUMETER(MM)	P.S.I	AVERAGE P.S.I.
1	100	20	16	25	23.6
2	100	20	18	22.2	

The heights in the volumeter was found to be 16 and 18 mm,while the protodyakonov impact index was found to be average of 25 and 22.2 ,that is 23.6.

On comparing the values of the sandstone samples and coal samples, the sandstone samples show high values. This may be due to the high silica content in the sandstone which increases the resistance to the sudden impacts given by the plunger weighing 2.4 kg.

4.3 LOS ANGELES ABRASION TEST

The Los Angeles abrasion test was not done on the coal samples because the coal sample did not provide any valid values. So the test was carried out on sandstone samples only. The initial weight of the samples was 5kg as given in the table.

It was found the weight of sample of retention after sieving was 1090 grams.

SERIAL NO.	**WEIGHT OF INITIAL SAMPLE**	**WEIGHT OF RETENTION AFTER SIEVING**	**% OF LOSS**
1	5000	1090	78.2

The percentage of loss in the abrasion test was calculated and it was found to 78.2%. This suggests that the sandstone sample is highly crushable in nature.

So there is similarity between the values of the slake durability tests and Los Angeles abrasion resistance test.

CHAPTER 5

Recommendations

CHAPTER 5

5.0 RECOMMENDATIONS

- Coal and sandstone samples are both important for the excavations underground as supports for the overlying strata, hence proper excavation designs are needed to improve the safety working conditions of the workers.
- Further study of the strength indices can be done and the interrelationships between the various strength indices can be derived from the values found.
- Empirical formulas between the strength indices can also be derived.

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